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Conservation Practices in Western Oregon Perennial Grass Seed Systems: III. Impacts on Gray-Tailed Vole Activity

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ABSTRACT

Decreased use of field burning to dispose of straw after harvest of temperate grass seed crops and the implementation of alternative conservation practices including direct seeding (DS) and maximal residue (HR) management have raised questions whether certain pests such as the gray-tailed vole (*Microtus canicaudus*) are worse than before these changes. The number of vole burrow holes was determined 15 Jan. 1999 at two research locations in western Oregon. Comparisons were made for the effects of DS and conventional tillage (CT) establishment, maximal and minimal residue (LR) management, present perennial seed crops, and immediate–prior crop in the rotation sequence and two-crops-prior in the rotation sequence. The treatments that most greatly influenced vole activity were crop establishment method and the previous crop in the rotation sequence. Vole activity was greatest in DS tillage establishment and when perennial grass seed was the prior crop in the rotation sequence. A possible production strategy to reduce vole activity could be to include meadowfoam (*Limnanthes alba* Benth.) or cereals in the rotation sequences when DS perennial grass seed crops are grown. This research demonstrates how vole activity can be reduced in perennial grass seed crops, without the need for tillage before establishment of new stands.

The gray-tailed vole is one of seven species found in the Pacific Northwest (USA) (Maser, 1998) and is the predominant species found in the Willamette Valley (Wolff et al., 1996). The gray-tailed vole was native to the once abundant prairie grasslands that are now dominated by agriculture. Gray-tailed voles now inhabit grass seed and grain fields, pastures, uncultivated field borders, and wild areas that comprise a significant portion of the landscape. In general, voles construct networks of surface runways and burrows where they live. Damage to grass seed and other crops by voles varies annually, but can cause substantial economic losses by grazing when population sizes peak (Krebs and Myers, 1974; Christie, 2005). The gray-tailed vole's breeding season in the Willamette Valley is March through November (Wolff et al., 1994).

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Vole population sizes vary greatly with cyclic peaks occurring every 4 to 6 yr. Predation rarely causes declines at times of vole population peaks (Krebs and Myers, 1974), but is believed to reduce the frequency of cyclic increases (Pearson, 1971). The causes of population fluctuations are not well understood, but have been reported to be influenced by amounts of cover (Birney et al., 1976), land use patterns (Delattre et al., 1992), food availability (Schultz, 1964; Batzli and Pitelka, 1970), predation (Smallwood, 1988), or diseases (Delattre et al., 1996). Populations of gray-tailed vole in the Willamette Valley are believed regulated by combinations of agricultural practices, habitat fragmentation, seasonal flooding, and predation (Wolff et al., 1996).

Voles are territorial and may occupy a home range of a few square meters, but they can also migrate to fields from bordering wild vegetated areas (Jacob, 2003). Voles generally avoid bare ground (Smallwood, 1996) that may increase exposure to predation (Preston, 1990), thus the amount of vegetative cover can affect vole predation by avian predators (Baker and Brooks, 1982). Willamette Valley avian predators have been shown to have a preference for short vegetation when hunting gray-tailed voles (Sheffield et al., 2001).

Reports of the effects of agricultural practices on vole populations in general are scattered. The height of vegetation and mulch after mowing has been shown to have no effect on common vole (*M. arvalis*) populations (Jacob, 2003). Use of direct-seed planting is reported to increase rodent damage to crops (Bourne, 1997; Smallwood, 1996), while tillage reduces populations (Jacob, 2003). Gray-tailed vole repopulation of plowed fields is dependent on recruitment from neighboring wild area refugia (Davis-Born and Wolff, 2000). Trampling during grazing by cattle (*Bos taurus*) can reduce small herbivore populations in grasslands (Hobbs and Mooney, 1995), while sheep (*Ovis aires*) grazing has no effect (Rebollo et al., 2003). Encouraging predator habitat may reduce gray-tailed vole populations (Sheffield et al., 2001).

Common vole populations were shown reduced following the harvest of beans (*Phaseolus vulgaris* L.), and their reproduction reduced after wheat (*Triticum aestivum* L.) harvest (Jacob, 2003). Voles show a food preference to acyanogenic white clover (WC, *Trifolium repens* L.) and have reduced intake when fed cyanogenic WC (Viette et al., 2000). Reproduction in rats (*Rattus norvegicus*) has been shown to be dramatically altered by phytoestrogens in red clover (RC, *T. pratense* L.) herbage (Saloniemi et al., 1995; Lamartiniere et al., 1998).

Abbreviations: ANOVA, analysis of variance; CT, conventional tillage; DS, direct seeding; HR, maximal residue; LR, minimal residue; PRG, perennial ryegrass; RC, red clover; TF, tall fescue; and WC, white clover.

This study was done to show what short-term effects conservation management practices suited to perennial grass seed production had on gray-tailed vole activity in Willamette Valley, OR. The research also identified possible short-term strategies to reduce vole activity.

MATERIALS AND METHODS

The scope of this study was to investigate the short-term effects perennial grass seed conservation management practices had on gray-tailed vole activity in the southern Willamette Valley, OR. Sampling was conducted on plots that were a part of long-term research sites that were maintained from 1992 to 2001 for the purpose of determining the effects of alternative conservation practices to burning or removing straw on temperate perennial grass seed production (Steiner et al., 2006).

Research Site and Management Practices Descriptions

One of the two sites sampled was a poorly drained Amity silt loam (fine-silty, mixed, superactive, mesic Argiaquic Xeric Argialbolls) in Linn County (Linn) in a commercial field (44°28′56″ N, 123°11′01″ W; 76-m elevation) where perennial ryegrass (PRG, *Lolium perenne* L.) and annual ryegrass (*L. multiflorum* Lam.) seed crops were grown. The other site was a poor to moderately well-drained Woodburn silt loam (fine-silty, mixed, superactive, mesic Aquultic Argixerolls) in Benton County (Benton) on the Hyslop Research Farm (44°38′01″ N, 123°12′01″ W; 70-m elevation) in an area where tall fescue (TF, *Festuca arundinacea* Schreb.) seed and other crops adapted to better-drained soil conditions are commercially grown. At both sites, 24 plots approximately 18 m wide by 34 m long were originally prepared in autumn 1991. The plots were arranged as four replicate blocks with six plots per block.

The common treatment practices to the sites were comparisons of: (i) CT vs. DS establishment, and (ii) minimal vs. maximal postharvest grass straw amounts returned to the field. A detailed description of operation used to apply these treatments is reported in Steiner et al. (2006). Tillage was done with a tractor-powered rotor-tiller to simulate the multiple tillage operations used by farmers when preparing the soil for planting. Following tillage, the plots were rolled twice to firm the seedbed for planting. Plots that were established by DS received nonselective herbicide applications to control weeds and volunteer crop seedlings. The entire 34-m length of plots were either tilled or not tilled.

Each 34-m long plot, regardless of tillage treatment, had previously been split into two 17-m long subplots with one subplot having all of the grass straw returned after harvest and the other half having the straw removed by raking and baling. The remaining full and minimal straw amounts left on the subplots were chopped twice or once, respectively, using a tractor-powered flail. The residue amount treatments were assigned at random. Only grass seed and cereal crops were used for the two residue management treatments. All residues produced by the meadowfoam, RC seed, and WC seed crops were returned to the plots.

Overview of Treatments in the Crop Rotation Sequences

A total of 14 treatment combinations from the 10-yr study (Steiner et al., 2006) were present from 1997 to 1999 for the period used to define this experiment (Table 1). The 14 treatments were comprised of nonfactorial combinations of: (i) perennial grass and clover seed crops of different stand ages at the time of sampling; (ii) rotation crops preceding the seed crops at sampling time; (iii) establishment methods; and (iv) locations of production. All treatments had comparisons of the two grass straw residue management amounts.

Perennial ryegrass seed was grown at Linn, and TF seed at Benton. The nongrass seed crops grown at Linn were WC, meadowfoam, spring wheat or spring oat (*Avena sativa* L.). At Benton, the rotation crops were RC grown for seed, meadowfoam, or spring wheat.

Vole Activity Measurement

Gray-tailed vole activity was expressed as the number of active burrow entrance holes counted on 15 Jan. 1999. Counting active entrance holes have historically been shown to be an index to the population size over a wide range of environ-

Table 1. Fourteen combinations of seed crops, crops in rotation sequences, and establishment methods at two locations in western Oregon used to determine the impacts of perennial grass (PRG) seed conservation practices on gray-tailed vole activity in 1999. The treatment combinations are for the period 1997 to 1999 within a 10-yr experiment beginning in 1992 and ending in 2001.

	Rotation crops†				Aggregate crop classes		
Present-crop†	Immediate–prior crop	Two-crops-prior	Establishment method‡	Location	Present crop§	Immediate–prior crop¶	Two-crops-prior#
PRG-1	MF	WC-1	DS	Linn	1	1	1
PRG-1	MF	WC-1	CT	Linn	1	1	1
PRG-2	MF	wheat	DS	Linn	1	1	2
PRG-2	MF	WC-3	DS	Linn	1	1	1
PRG-2	MF	WC-3	CT	Linn	1	1	1
WC-1	oat	PRG-4	DS	Linn	2	2	3
PRG-1	MF	wheat	DS	Linn	1	1	2
PRG-2	PRG-3	PRG	CT	Linn	1	3	3
RC-1	wheat	TF-2	DS	Benton	2	2	3
RC-1	wheat	wheat	CT	Benton	2	2	2
TF-1	MF	RC-2	DS	Benton	1	1	1
TF-1	MF	TF-2	CT	Benton	1	1	3
TF-est††	TF-2	TF	CT	Benton	1	3	3
TF-est	TF-2	TF	DS	Benton	1	3	3

† Crop and rotation crop abbreviations: PRG, perennial ryegrass seed; WC, white clover seed; RC, red clover seed; TF, tall fescue seed; and MF, meadowfoam. Crop abbreviations followed by a number indicate the seed crop year for a perennial stand.
‡ Establishment methods: DS, directed seeded; CT, conventional tillage establishment.
§ Present-crop aggregate classes: 1, perennial grass seed; 2, clover seed.
¶ Prior-crop aggregate classes: 1, meadowfoam; 2, cereals; 3, perennial grass seed.
# Two-crops-prior aggregate classes: 1, perennial clover seed; 2, cereals; 3, perennial grass seed.
†† est, establishment year.

Table 2. Effects of location, grass species, clover species, and cereal type at two western Oregon locations used to determine the impacts of perennial grass seed conservation practices on gray-tailed vole activity measured as burrow access holes in 1999.

Variable	Location		Grass species†		Clover species‡		Cereal–location§		
	Linn	Benton	PRG	TF	WC	RC	W–L	O–L	W–B
	holes m^{-2} × 100								
Vole activity	13.6	15.8	13.0	16.1	17.3	15.1	20.0	17.3	15.1
n	64	48	56	32	8	16	8	8	16
Difference	NS¶		NS		NS		NS		

† Grass species: PRG, perennial ryegrass seed; TF, tall fescue seed.
‡ Clover species: WC, white clover seed; RC, red clover seed.
§ Cereal–location: W–L, spring wheat at Linn; S–L, spring oat at Linn; W–B, spring wheat at Benton.
¶ NS, not significant at $P \leq 0.05$.

ments (Liro, 1974). The time of counting in this experiment was during the winter period before the time gray-tailed vole populations increases with reproduction (Wolff et al., 1994). Active burrow entrance holes were determined visually by the presence of fresh soil at the entrance mouth. The burrow entrances that did not appear active were easy to distinguish from the active entrances and were not counted. Voles were active during this time of the year and plant cover and remaining residue amounts were minimal. It was assumed only gray-tailed voles were the species present because of the consistent size of the burrow entrances and its dominance within this kind of landscape (Wolff et al., 1996).

The number of active burrow entrance holes were counted within 1 m of each side of a 30-m long transect that ran diagonally across each grass straw residue amount subplot at both research sites. The approximate area surveyed in each subplot was 60 m^2. A total of 48 and 64, 18-m wide by 17-m long plots were sampled at Benton and Linn, respectively.

Data Analysis Methods

Six arbitrary categories of variables were hypothesized to possibly affect vole activity: (i) present-time crop when voles were sampled, (ii) immediate–prior crop to the present crop in the rotation sequence, (iii) two-crops-before the present crop in the rotation sequence, (iv) establishment methods, (v) residue management amounts, and (vi) locations. It was also hypothesized that crops of similar life histories would have similar impacts on vole activity.

To test for differences among the hypothesis groups, a series of one-way analyses of variances (ANOVA) were used to decide if the data could be pooled for grass species (PRG and TF), clover species (WC and RC), and cereal–location combinations (Wheat–Linn, Oat–Linn, Benton–Wheat) (Table 2). As a result of the one-way ANOVAs, four aggregate crop classes were produced with the present-time crop variable defined as perennial grass or clover seeds; establishment method variable defined as DS or CT; the immediate–prior crop variable defined as meadowfoam, cereal (wheat or oat), or perennial grass seed; and the two-crops-prior variable was clover, cereal, and perennial grass seed. Using the four defined classes of variables, eight final management treatment combinations were identified (listed in Table 3). The other production practice variables were defined as establishment method (DS or CT), residue management amount (maximal or minimal), and location (Linn or Benton).

An exploratory multivariate factor analysis (Hair et al., 1995, p. 367) was used to determine associations among six variables and to find which were associated with vole activity. The factor analysis was done using orthogonal rotation factor rotation by the varimax method (Table 4). Spearman's rank correlation tests (Sokal and Rohlf, 1981, p. 607) were used to determine which associations among the related variables within each factor were significant. One-way ANOVAs were also used to test for differences among treatment levels within the six variables. Fisher's protected Least Significant Difference test (Snedecor and Cochran, 1980, p. 234) was used to separate means (Table 5).

Based on the factor analysis results, the immediate–prior crop and establishment methods variables were found the most strongly loaded variables associated with rodent activity, so an ANOVA model was used to determine the treatment effects for immediate–prior crop (P), blocks (B), establishment methods

Table 3. Eight management treatment combinations comprised of present crop, establishment methods, immediate-crop-prior, and two-crops-prior used to determine gray-tailed vole activity in 1999 in western Oregon. The resulting treatments are the aggregate results from all plots shown in Table 1 after testing for mean differences as shown in Table 2.

Treatment	Present crop†	Establishment method‡	Immediate-prior crop§	Two-crops-prior¶	Number of plots
					n
1	grass	DS	MF	clover	24
2	grass	CT	MF	clover	16
3	grass	DS	MF	cereal	16
4	grass	CT	MF	grass	8
5	grass	DS	grass	grass	8
6	grass	CT	grass	grass	18
7	clover	CT	cereal	cereal	8
8	clover	DS	cereal	grass	16

† Present crop: grass, perennial grass seed; clover, clover seed.
‡ Establishment methods: DS, directed seeded; CT, conventional tillage establishment.
§ Immediate–prior crop: MF, meadowfoam; cereal, spring wheat or spring oat; grass, perennial grass seed.
¶ Two-crops-prior aggregate classes: clover, perennial clover seed; cereal, spring wheat or spring oat; grass, perennial grass seed.

Table 4. Multivariate factor analysis of perennial grass and clover seed crops, crop rotation components, and conservation practices effects on gray-tailed vole activity in 1999 in western Oregon.

Variables	Factors				
	Rotation crops	Establishment method	Present crop	Location	Residue amount
	rotated factor loadings†				
Immediate–prior crop	*0.905*	0.073	0.077	0.164	0.005
Two-crops-prior	*0.808*	0.036	0.296	0.0235	0.010
Vole activity	*0.540*	*−0.686*	−0.253	−0.073	−0.067
Establishment method	0.262	*0.866*	−0.210	0.010	−0.024
Present crop	0.202	−0.074	*0.926*	0.090	−0.007
Location	0.251	0.038	0.094	*0.957*	0.003
Residue amount	0.004	0.007	−0.005	0.002	*0.999*
Variance explained	27.6	17.6	15.3	14.5	14.3

† Rotated factor loading shown in italic font within the same factor indicate variables that are correlated with one another at $P \leq 0.05$ according to Spearman's rank correlation test.

Table 5. The effects of management practices on gray-tailed vole activity measured as burrow access holes at two western Oregon locations in 1999.

							Rotation crops					
	Establishment method†		Residue amount‡		Present-crop§		Immediate–prior crop¶			Two-crops-prior#		
Variable	DS	CT	Min	Max	Grass	Clover	MF	Cereal	Grass	Clover	Cereal	Grass
	holes $m^{-2} \times 100$											
Vole activity	18.6	8.8	15.5	13.5	14.2	15.8	9.8 b††	15.8 b	25.7 a	11.1 b	8.0 b	20.6 a
n	64	48	56	56	88	24	64	24	24	40	24	48
Difference	**		NS		NS			**			*	

* Significant at $P \leq 0.05$. NS, not significant.
** Significant at $P \leq 0.01$.
† Establishment methods: DS, directed seeded; CT, conventional tillage establishment.
‡ Reside amount: minimal and maximal amount returned to field.
§ Present-crop aggregate classes: 1, perennial grass seed; 2, clover seed.
¶ Prior-crop aggregate classes: 1, MF, meadowfoam; 2, cereals; 3, perennial grass seed.
# Two-crops-prior aggregate classes: 1, perennial clover seed; 2, cereals; 3, perennial grass seed.
†† Means in the row followed by the same letter are not different according to Fisher's protected Least Significant Difference test at $P \leq 0.05$.

(E), residue management amount (R), and their interactions (Table 6). The model for this design was:

$$y_{ijkl} = \mu + P_i + B_j + PB_{ij} + \delta_{(ij)} + E_k + PE_{ik} + PBE_{ijk} + R_l + PR_{il} + ER_{kl} + PER_{ikl} + PBER_{ijkl} + \varepsilon_{(ijkl)}$$

The restriction on the randomization due to blocking was represented by $\delta_{(ij)}$. The mean square for the PB interaction was used to test the P effect. The mean square for PBER was used to test for differences in the E, PE, PR, ER, PBE, and PER effects. Means separations were done using Duncan's New Multiple Range test (Damon and Harvey, 1987, p. 165.). All differences reported are significant at $P \leq 0.05$, unless otherwise stated.

RESULTS

Two factors were found to influence vole activity: the method of crop establishment and the kinds of crops in the rotation sequence immediately preceding the present crop (Table 4). The kind of present seed crops being grown (grass or clover), residue management amounts, and the locations of production were independent of one another (Table 4) and did not affect vole activity (Table 5). The crops grown two-crops-prior in the rotation sequence were not as influential on vole activity as the immediate–prior rotation crop, as indicated by the lower rotated loading value in the factor analysis (Table 4).

Direct-seeded, continuous perennial grass seed as the previous crop in the rotation sequence resulted in the greatest vole activity of all treatment combinations (Table 7). Vole activity was reduced if CT was used for establishment of the continuous grass crop. Alternatively, inserting meadowfoam or spring cereals into the crop rotation sequence provided as great of a reduction in vole activity in the present crop as using CT establishment. Cereals as the immediate–previous crop when established by CT resulted in the lowest vole activity in the present-crop of all treatment combinations. Use of a meadowfoam rotation crop reduced vole activity more than wheat in a DS system.

Table 6. Summary of analyses of variance for comparing the effects of the immediate–prior crop in the rotation sequence, establishment methods, and residue amounts on long-tailed vole activity in western Oregon perennial seed crops in 1999.

Sources of variation	Degrees of freedom	Significance level
Immediate–prior crop (P)	2	*
Establishment method (E)	1	***
Residue amount (*R*)	1	NS
P × E	2	**
R × R	2	NS
E × R	1	NS
P × E × R	2	NS

* Significant at $P \leq 0.05$. NS, not significant.
** Significant at $P \leq 0.01$.
*** Significant at $P \leq 0.001$.

DISCUSSION

Established western Oregon perennial grass seed stands likely provide a more stable medium for vole populations than do annual crops such as autumn-planted meadowfoam or spring cereals. The use of a DS, continuous grass seed system provides a relatively continuous habitat for voles that is conducive for maintaining a habitat similar to undisturbed grassy areas near fields. Tillage disrupts the network of vole pathways on the soil surface as well as underground burrows, and likely causes mortality and reduces available diet resources (Bourne, 1997, Brown et al., 1998, Jacob, 2003). Also, voles are weak diggers compared with other fossioral mammals, so destruction of burrow systems would likely cause substantial delayed colonization in fields after tillage (W.D. Edge, personal communication, 2005). However, there are other factors

Table 7. The effects of kind of immediate–prior crop in the rotation sequence and establishment method on long-tailed vole activity measured as number of burrow access holes in western Oregon perennial seed crops.

Immediate–prior crop	Establishment method†	Vole activity	Number of plots
		holes $m^{-2} \times 100$	*n*
Meadowfoam	DS	10.3 cd‡	40
Meadowfoam	CT	9.0 cd	24
Cereal	DS	23.1 b	16
Cereal	CT	1.3 d	8
Continuous grass seed	DS	52.5 a	8
Continuous grass seed	CT	12.4 c	16

† Establishment methods: DS, directed seeded; CT, conventional tillage establishment.
‡ Means in the column followed by the same letter are not different according to Duncan's New Multiple Range test at $P = 0.05$.

to consider when using tillage to suppress vole activity. Even though vole activity may be reduced by tillage, the disadvantages of tillage before seeding include increased establishment cost, decreased seed yields, and increased soil erosion (Steiner et al., 2006).

Lower vole activity can be achieved in DS systems when meadowfoam and cereal crops are inserted into the rotation sequence (Table 7). This may be due to these annual crops providing much less cover during winter and early spring than established perennial grass seed stands. Meadowfoam and cereal crop canopies do not expand until ambient temperatures rise in spring, leaving inter-row areas exposed. Also, with meadowfoam and cereals (as well as clovers), relatively little cover remains after summer harvest because of the friable nature of the residues. This results in less summer cover being provided, compared with perennial grasses that have dense crowns arranged in 0.3-m wide rows. *Microtus* populations in Germany have been shown to be decreased following bean, another crop with friable vegetation, as well as after wheat harvest (Jacob, 2003).

The lack of effect due to residue management may have resulted from inadequate difference between the maximal and minimal chopped straw amounts left in fields after seed harvest. Similarly in another study, mulching or mowing had no effect on vole population sizes in perennial grass stands (Jacob, 2003). From our results, it appears that full straw chop-back may not affect short-term vole activity in perennial grass seed fields.

Grass plant crowns begin regrowth after harvest, with typical remaining residue amounts for minimal and maximal chopped straw treatment being 1800 and 12000 kg ha^{-1} after harvest, respectively (Steiner et al., 2006). These amounts are less than the threshold cover reported to provide diet resources needed to support *Microtus* population cycle increases in U.S. central plains states (Birney et al., 1976). Also, maximal chopped residue mass begins decomposition with the onset of dew formation in September, and are reduced 60% by early May (Steiner, unpublished data, 2005). In addition, a majority of Willamette Valley grass seed growers (80–85%) have as much straw as possible removed by baling on the 165000 ha of perennial ryegrass and tall fescue fields (Steiner et al., 2006). It is therefore likely that factors other than grass cover amount contribute to vole population cycling.

Another factor that may influence vole activity is the amount of seed left in fields after harvest. Voles are dependent on available food sources to maintain population size (Schultz, 1964; Batzli and Pitelka, 1970). Perennial grass and clover seed crops may leave great amounts of seed on the ground due to seed shattering during harvest (Klein and Harmond, 1971; Oliva et al., 1994). Both cereals and meadowfoam have much less shatter losses than grass and clover plants grown for seed, so less food would be available for feeding. This may suggest why the grass and clover seed crops following these crops in the rotation sequence had lower vole activity, even when DS.

It is unlikely that chemical constituents in clover herbage affected vole activity to cause differences among crops in our small-sized plots. However, at a larger field-scale, it may be possible that secondary plant products in clover herbage consumed by voles could influence vole populations. Cyanogenic glycosides in WC may affect diet intake (Viette et al., 2000) that indirectly impacts reproduction, and phytoestrogens in RC may directly reduce reproductive success (Saloniemi et al., 1995; Lamartiniere et al., 1998).

CONCLUSIONS

This research measured vole activity in one production year at two locations with a diversity of controlled production conditions. Vole activity was the greatest when direct-seeded perennial grass was the immediate–previous crop in the rotation sequence. Vole activity could be reduced in all treatment combinations by using CT establishment. However, inserting meadowfoam or spring cereals into the grass seed crop rotation sequence provided as great of a reduction in vole activity as using CT establishment. Long-term research is needed to determine how different production strategies identified in this study may alter vole population cycles at a landscape level. However, this research provides some in-field management options to consider that may reduce vole activity at the local level.

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